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EXPLOSIVES RESEARCH & DEVELOPMENT ESTABLISHMENT

TECHNICAL MEMORANDUM No. 21/M/52

Sensitiveness of Solid and Liquid Explosives:

Part 3: The Application of the Gap Test to Liquid Explosives

R. Pape and E. G. Whitbread

Waltham Abbey Essex. RESTRICTED March 1953

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by

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CONTENTS

Reference: XR. 300/32.

1. SUMMARY

The work described in this Technical Memorandum is part of a general investigation into the sensitiveness of liquid explosives. A technique for the determination of the sensitiveness to shock of liquid explosives in moderate bulk (of the order of 100 ml.) has been developed. This is giving reliable results with explosives which are less sensitive than ethyl nitrate and more sensitive than propyl nitrate.

The work has shown the necessity of distinguishing between ease of initiation and ease of propagation; tests which do not so distinguish are of limited application only. A number of explosives have been placed in a scale of sensitiveness.

No attempt has been made to give a theoretical background; indeed it is held that the present state of knowledge of the factors involved is inadequate. Steps to remedy this deficiency are outlined.

2. INTRODUCTION

It is well known that to obtain a meaningful result from a test of sensitiveness of the falling weight type, large numbers of individual experiments must be statistically treated. A further drawback is that this type of test does not lend itself to the examination of other than small samples, and the application of the results to larger quantities is uncertain. It has been noted by Eyring (1) that results of tests of sensitiveness involving pure shock are not so prone to experimental variation as those of the falling weight type. Tests quoted by this author include impact stresses by filled aircraft bombs falling on to concrete, the use of a rifle bullet as a striking device, minimum primer tests in which the size or composition of the primer is varied, and the 'gap' tests.

Results from rifle bullet attack have been described elsewhere (2). In a choice between 'primer' and 'gap' tests it was decided that the 'gap' test was preferable in view of the simpler (although still formidable) provision requirements.

Both these techniques are similar in principle - in each the test assembly consists of a detonator together with a priming charge (which the detonator always explodes) and a test charge which may or may not be exploded by the detonator and primer. In the minimum primer technique the primer and test charge are in contact and the size of the primer is varied; or alternatively the primer itself is of a standard size but made of a mixture of inert and explosive material, the proportions of which can be varied; the results being expressed as the minimum primer (in size or energy) to produce a given effect, ideally to just initiate the charge under test. In the 'gap' test the primer is standard in all respects but is separated from the charge under test by a gap of some inert material (e.g. air). The only variables are the explosive charge and the size of the gap. The minimum primer test requires therefore a large stock of finely graded primers of both sorts; the 'gap' test requires a supply of one size of primer and a stock of finely graded 'gaps'. This latter requirement seemed the simpler and the 'gap' test was therefore adopted.

/3. EXPERIMENTAL DETAILS

3. EXPERIMENTAL DETAILS

3.1 Definitations.

With the 'gap' test, a certain nomenclature has grown up which requires definition. The detonator/primer assembly which provides the initiating shock in the first instance, is called the 'donor charge', or more simply the 'donor'. The layer of inert material between the 'donor' and the charge under test is always called the 'gap' even though it is often filled with solid material. The actual charge tested, i.e. the sample of explosive in its container as assembled ready for firing, is called the 'acceptor charge' or 'acceptor'. The testing of liquid explosives renders the use of a container obligatory and the exact form of this is found to have a profound effect on the results. The container is called the 'charge case' since the 'donor' in the experiments described here, is always bare. An 'acceptor' is said to have 'fired' if under the influence of the shock wave it has released an arbitrarily-defined and experimentally-detected amount of energy. In some of the early work the term 'partial', which denoted the release of energy in detectable amounts but below that required for a 'fire', was used; this term however, because of the looseness of its definition, led to somewhat subjective conclusions and was dropped. The alternative to a 'fire' is that a charge 'fails'.

As might be expected, the critical dimensions of the 'gap' needed to produce a given effect are very dependant on the particular combination of 'donor charge', 'charge case' and the material from which the 'gap' is made. All these are rigorously defined for any particular series of experiments and the collective specification is designated the 'scale'. Thus 'Scale I' refers to the results obtained with one combination,'Scale III' those obtained with another and so on.

The critical dimension of the 'gap', which is a measure of the sensitiveness of the explosive under test, is the separation of 'donor' and 'acceptor' charges in the experiments which produce the desired result, i.e. the acceptor just failing or just firing. All the work described in this memorandum has been done with cardboard 'gaps' and the results are expressed as a 'critical card value' which is the number of cards of thickness 0.05 inch which have been used to make the critical gap. This number expresses the sensitiveness of the explosive under test and increases with increasing sensitiveness.

3.2 Scale I.

The assembly specified for 'Scale I' is shown in Fig.1. The detonator is a standard commercial No.8 Briska type: this has the now standard hollow or dimpled end the jet from which, with small gaps, would seriously enhance the effect of the shock entering the bottom of the acceptor. The detonator is not therefore coaxial with the charge it initiates, as is the usual practice, but is placed perpendicular to the axis (Figs.1, 2).

The donor consists of two cylindrical one-inch-diameter tetryl pellets, pressed to a density of 1.5 grams/millilitre and each 10 grams in weight. Originally one 20 gram pellet was used but the change to 10 gram pellets enabled a much smaller pellet stock to be maintained. (These pellets are used, made up into charges of varying weight, in other work). Further, since they are made in a single-ended press, the use of two pellets instead of one will give a much more uniform distribution of density throughout the donor charge. The end of greater density is in all cases placed nearest the acceptor.

The gap is composed of a stack of cards, three inches square, cut from standard Stationery Office stock described as "16 sheet pasteboard, white" - this is actually 0.050 inches thick. The cards are cut square because this is the

/easiest

easiest shape to cut with an ordinary treadle guillotine. They are made this particular size for this scale since it was found in early work that the cross-sectional area of the gap should exceed that of the donor or acceptor, whichever is largest, by at least 50 per cent if the high standard of reproducibility, previously noted as applying to shock tests, is to be obtained. A further somewhat generous margin had to be allowed to cover errors in cutting since large numbers were required and this task was performed in the main by semi- or unskilled labour.

The charge case consists of a six inch length of mild steel electrical conduit 27 mm.I.D. 31 mm.O.D. known to the trade as 'one inch' or 'inch and a quarter' according to the thread on the uncut length. Originally the case was nine inches in length but it was found that this length could, with advantage, be reduced to six inches. One end of the case is faced square with the axis and two wire hooks are brazed near this end. The faced end is sealed with a 0.001 inch thick piece of tinfoil cemented on eith either "Necol" varnish or "Durofix" cement. This prepared end becomes the bottom of the case and rests on the card stack. An elastic band of suitable length passes from one hook, under the card stack, pellets and detonator and up to the other hook. This elastic band performs the dual function of holding the entire assembly together and of providing a consolidating pressure on the card stack. The purpose of the foil is to prevent liquid explosives soaking the top card; its effect on the shock is negligible in comparison with a single card; it has been found possible without effect on the results to replace it by a 0.003 inch thick sheet of polyvinyl chloride, a modification which has enabled explosives containing nitric acid to be tested.

When ready for firing the assembly is suspended by strings at the centre of a large square steel frame. This method of support requires only the replacement of the string and, at very long intervals, repairs to the frame.

When an assembly has been fired the contribution of the acceptor to the explosion is assessed by reference to the condition of the charge case. Ideally the case will be but little distorted by the shock from the donor as transmitted by the gap, but reduced to fragments by an exploding acceptor. In fact, with Scale I assemblies, the first condition is only partially met in that, with gaps of less than 15 cards, a water filled tube splits and the pieces between the splits are rolled back: With gaps of less than 7 cards it is reduced in length. The second condition is fulfilled by explosives which are 'good propagators', that is, those explosives in which a detonation wave, once set up, propagates freely. Explosives may be quite sensitive, but poor 'propagators', and the detonation or explosion wave will die rapidly, leaving the top part of the tube intact or, at the most, split. In spite of this drawback, interesting and useful work has been done with explosives of properties as different as those of D.E.G.N.(3), lightly loaded picrite (4) and others mentioned in Table 4, Appendix I.

Since a primary interest of this Establishment is safety, it was decided to adopt, as a definition of the critical gap, that gap which would just prevent the initiation of the acceptor, rather than the gap which would result in (say) 50 per cent fires. The sensitiveness is thus defined in terms of the minimum energy required to give explosions. If the main interest were in efficient explodering, it would obviously be more profitable to adopt the other extreme, i.e. the gap which just permits all the acceptors to fire; the two scales will not necessarily be in the same order since it is possible to envisage explosives with wide or narrow spreads in this respect. It is not possible to say that any particular gap will not give any explosions without an infinite number of tests; it was therefore arbitrarily laid down that the critical gap should be that gap which gave four failures in the first four shots, together with at least one fire in the first four shots using a gap one unit smaller. The critical gap should always be approached in the same way, and the scheme in Appendix II ensures this.

/The

The limitations of this scale are:

(i) Lower limit for the gap of 5 cards, below which there is evidence that hot particles from the donor break through, involving initiation by other mechanisms than by shock,

(ii) An upper limit not exactly defined but certainly below 50 cards, at which the shock waves produced are not reproducible, and

(iii) The necessity of working with an acceptor which gives stable detonations under these test conditions.

3.3 Scale III.

The assembly specified for Scale III is shown in Fig.2. The essential differences from Scale I are as follows:

Donor - two twenty gram pellets of tetryl, pressed to a density of 1.5 g/ml. each 1.5 inches in diameter,

Gap - 4 inch square cards, otherwise as for Scale I,

Charge Case - a three inch length of $1\frac{1}{2}$ inch steam pipe (actually a welded seam pipe $1\frac{7}{8}$ inch O.D. by 8 gauge) faced at both ends, hooks as for Scale I,

Test Plate - a 3 inch square of 16 gauge mild steel. This is placed on the top of the filled charge case.

In comparison with Scale I the explosive under test is subjected to a higher pressure for a given gap and the charge case is shorter and wider thus reducing the need for good propagation of detonation in the acceptor. The combination of higher shock pressures and shorter charge case has increased the difficulty of judging the result of a test. This difficulty is overcome by the use of the test plate which is placed on the top of the filled charge and becomes, effectively, the end of the charge case. It is well known that the end of a charge case suffers more severe fragmentation than the sides; the fragmentation of the test plate is, therefore, a much more sensitive indication of detonation within the acceptor than that of the charge case itself. Figs. 3 and 4 effectively illustrate this point. Fig.3 shows a charge case with test plate which was filled with water and subjected to the shock transmitted by a 10 card gap: the high power of the shock has severely distorted the tube into a bell shape and produced a bulge in the test plate. Fig.4 shows a similar charge case and test plate which was filled with a 60/40 ethyl nitrate/propyl nitrate mixture and subjected to the shock transmitted by a 24 card gap. There has been but little 'belling' of the tube as the shock is weaker. Had there been no initiation of the acceptor no doubt the bulge in the test plate would be even less than in Fig.3. The bulge in the top of the tube is due to the partial explosion of the filling, and the test plate is broken into fragments. Since, however, the results obtained were not so definite as those obtained with 'Scale I' (using suitable explosives) the criterion for the 'critical card value' was changed from four failures to ten.

Scale III has proved to be a reliable test for explosives in the sensitiveness range, ethyl nitrate to propyl nitrate. With explosives less sensitive than propyl nitrate the size of the gap becomes rather small, and there is a limit of about 45 to 50 cards where the reproducibility of the shock wave becomes poor. Examples of the results obtained are given in Table 5, Appendix I.

/4. REPRODUCIBILITY.

4. **REPRODUCIBILITY**

Tests for reproducibility of the results obtained by means of the gap test under different conditions are still in progress. Tests of the reproducibility of the results obtained with actual explosives are made as follows. A card value is determined in the usual way, a large number of shots (usually 50) are then fired with gaps equal to this card value and for a sequence of gaps several units on either side of it. Thus, with a mixture of 60 per cent ethyl nitrate and 40 per cent propyl nitrate the card value was found to be 27, Scale III. 50 shots were then fired with gaps of 25, 26, 27 and 28 cards producing the result in Table 6, Appendix I. These results may be treated statistically in the usual way, e.g. by the use of probits (5). This involves, however, the determination of some function of the gap with respect to which the percentage fires are normally distributed. For air gaps, Rajchenbaum (5) finds that this function is the square of the gap. The present authors do not feel that there is sufficient evidence to establish a definite relation for the card gaps; they have found, in work to be published later, that the logarithm of the pressure generated by the donor/gap assembly, as measured by the Hopkinson pressure bar (6), is a linear function of the card value from 15 to 50 cards; it is therefore a distinct possibility that the required function in this case will be exponential in form.

In view of this uncertainty we have determined the probability (for Scale III) of 10 failures in the first 10 shots at any of the card values tested; two assumptions are made. One, the percentage fires for each card value is the same for an infinite population of tests at this card value as for the sample of 50 shots. This means that the random selection of a particular result does not affect the proportion of fires in those left. Two, the critical card value is always approached from the direction of lower values; this is a consequence of the scheme laid down in Appendix II and enables a correction to be made for the probability that 10 failures in the first 10 shots will have occurred at a lower card value.

From the first assumption, considering the case illustrated in Appendix I Table 6, the probability of 10 failures in the first 10 shots for 25 cards is $(0.48)^{10}$ or 0.0008. The probability of 10 failures in the first 10 shots for 26 cards is $(0.62)^{10}$ or 0.008 (ignoring the small correction due to the 25 card result), and for 27 cards is $(0.98)^{10} = 0.817$. In a large number of trials, since firing always starts at the low card values, 99.12 per cent of the trials will have given at least one fire in the first ten shots at 25 and 26 cards, so that the probability that no fire will occur in the first ten shots at 27 cards is 0.9912 x 0.817 i.e. 0.810. The probability that the first 10 shots at 28 cards will fail is $(0.96)^{10}$ or 0.665, multiplied by a factor of 0.182 since only 18.2 per cent of the trials will have survived the previous tests, this gives a result of 0.121 for this card value. These results are collected in Table 1. (p.6) This ignores the very small probability of a value below 25.

Other results are for ethyl nitrate and propyl nitrate (Tables 2 and 3).

Scale I has not been studied by this method. This scale has the additional complication that of those experiments resulting in initiation, only a proportion will propagate sufficiently well to give a positive result. An examination of the results obtained in connection with the investigation into the effect of bubbles on sensitiveness has shown that out of 36 shots fired at 27 cards with D.E.G.N. as the acceptor none resulted in fires, out of 28 shots fired at 25 cards, none failed, on the other hand any given mixture of nitromethane and D.E.G.N. can be given a number of critical card values depending on the exact definition of the condition of the tube accepted as a fire.

/TABLE 1

TABLE 1

Probable Critical Card Value for 60/40 Ethyl/Propyl Nitrate.

Card Value	Probability
25	0.0008
26	0.008
27	0.810
28	0.121
> 28	0.060

TABLE 2

Probable Critical Card Value for Ethyl Nitrate.

Card Value	Probability
41	0.021
42	0.135
43	0.458
44	0.316
> 44	0.071

TABLE 3

Probable Critical Card Value for n-Propyl Nitrate.

Card Value	Probability
13	0.00001
14	0.17
15	0.23
16	0.54
> 16	0.06

/5.

5. CONCLUSIONS AND OUTLINE OF FUTURE WORK

The gap test is a powerful tool in the investigation of problems involving sensitiveness to shock. It is important in this work to distinguish clearly between initiation and propagation of explosion. Sensitiveness is primarily a measure of ease of initiation; the gap test, as described, is best suited to determine initiation and therefore the effects of variable propagating power must be minimised. This has been done with a fair measure of success for explosives which are as sensitive as propyl nitrate but no more sensitive than ethyl nitrate, in the Scale III type of test.

The major problems outstanding are:

(i) To extend this technique to a larger range of explosives, particularly to solid and high energy liquid explosives,

(ii) To reduce, if possible without losing the 'bulk' character of the test, the quantity of material needed for a trial,

And (iii) to determine by what mechanism the shock initiates the acceptor, the latter problem having considerable fundamental importance.

Work is in hand to determine the history, in terms of pressure and velocity, of the shock in its passage from the donor to the point of initiation of the acceptor. The effect of changes in the structure of the test assembly, e.g. the role of the confinement of the acceptor, are also being studied. The techniques used include the Hopkinson pressure bar and optical determinations on shock waves in condensed media. Determinations of the dependence of the pressure and duration of the shock on donor cross-sectional area and length, and also on card value, have been made and will be published when complete.

6. ACKNOWLEDGMENTS

The authors gratefully acknowledge help received in discussions with Dr. K.A. Cooper and Mr. L.A. Wiseman. Although he was not concerned with the development of the test much of the subsequent operational firing was carried out by Mr. E. Speller.

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/APPENDIX I

APPENDIX I

TABLE 4.

Examples of Scale I Card Values.

Explosive		Critical Card Value
N.G./triacetin 90/10	ø	65
Ethylene glycol dinitrate/triacetin 89/11	ø	52
N.G./triacetin 85/15	ø	47
E.G.N./triacetin 82½/17½		31
N.G./triacetin 82½/17½		31
E.G.N./triacetin 80/20		27
D.E.G.N.		27
N.G./triacetin 80/20		26
Pressed amatol 80/20 (1.3 g/cc)	*	25
Cast pentolite 50/50	*	25
Pressed pentolite 50/50 (1.3 g/cc)	*	23
R.D.X./B.W.X.	*	23
D.E.G.N. + 10% collodion cotton		23
N.G./triacetin 75/25		22
E.G.N./triacetin 75/25		21
Picrite (0.67 g/cc. at 95°C)	*	18
Picrite (0.67 g/cc, at ambient)	*	18
Picrite (0.33 g/cc, at 95°C)	*	17
Picrite (0.33 g/cc, ambient)	*	16
Dithekite D.13		16
Cast T.N.T. (normal brown)	*	9
Dithekite D.20	ø	4
N.G./triacetin 70/30		< 5
D.E.G.N./triacetin 90/10		< 5
2.3-Butanediol dinitrate		< 5
Nitromethane	ø	3
Ethyl nitrate	ø	2
Cast double-base cordite	* ø	1

* The correlation between liquids and solids (included here for completeness) on one scale is as yet uncertain.

ø Results outside limits set in Appendix II.

/TABLE 5

TABLE 5.

Examples of Scale III Card Values.

Explosive	Critical Card Value
Ethyl nitrate	43
2.3-Butanediol dinitrate/ethyl alcohol : 96/4	40
Ethyl nitrate/propyl nitrate 80/20	37
Ethyl nitrate/ethyl alcohol 96/4	35
N.G./triacetin $67\frac{1}{2}/32\frac{1}{2}$	29
2.3-Butanediol dinitrate/ethyl alcohol 92.1/7.9	31
Ethyl nitrate/ethyl alcohol 92.1/7.9	29
Ethyl nitrate/propyl nitrate 60/40	27
N.G./triacetin/carbamite 65/34/1	25
N.G./triacetin 65/35	24
Nitromethane	24
Ethyl nitrate/ethyl alcohol 84.1/15.9	22
2.3-Butanediol dinitrate/ethyl alcohol 84.1/15.9	22
Ethyl nitrate/ethyl alcohol 80.1/19.9	19
2.3-Butanediol dinitrate/ethyl alcohol 80.1/19.9	18
N.G./triacetin 60/40.	16
n-Propyl nitrate	16

/TABLE 6

TABLE 6.

Summary of Observed Results for 60/40 Ethyl Nitrate/ Propyl Nitrate for Card Values of 25 to 28.

Card Value	Results 1 = Fire 0 = Fail	Percentage Fires
25	0 0 0 1 1 0 0 0 0 0 0 0 0 0 0 1 1 1 1 1 0 0 0 1 1 0 0 0 1 1 1 1 1 1 1 0 1 1 1 0 1 1 0 1 0 1 0 1 1 1	52
26	0 0 1 1 0 0 0 1 0 0 0 1 1 1 0 1 0 0 0 1 0 1 1 0 1 1 0 0 0 1 1 1 1 0 0 0 0 1 1 1 0 0 0 0 0 0 0 0 0 0	38
27	0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	2
28	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 1 0 0 0 0	4

/APPENDIX II

APPENDIX II

Scheme to Determine the Order in which Card Values Are Used.

(i) Scale I.

(a) Try one shot at an arbitrary level 'L'. If a fire results proceed as from (b), if a fail, proceed as from (c).

(b) Increase by 10 units (cards) at a time until at L + 10x units a fail results.

(c) Decrease by 5 units (i.e. to L + 10x -5). If a fire proceed as from (d). If a fail decrease by 2 units at a time until a fire results, then proceed from (d).

(d) Increase by one unit and try shots at this level until either the first four shots have all failed (in which case this level is the critical card value) or a fire has been obtained; if the latter, repeat as from (d) until the first four shots at any level have failed.

(e) If a fail results at (a) decrease by 10 units at a time until at a card value of L - 10x a fire is obtained, then increase by 5 units; if a fire then results proceed as from (d); if a fail then decrease by 2 units at a time until a fire results, then proceed as from (d).

(ii) Scale III.

The procedure is similar to Scale I except that the criterion for the critical card value is 10 failures in the first 10 shots instead of 4 (Section(d)).

(iii) Limits.

The limits (Sections 3.2 and 3.3) for the two scales are:

Scale I, lower 5 cards, upper 45 cards.

Scale III, lower 10 cards, upper 45 cards.

Firings are not normally carried out beyond these limits. For Scale I, a single fire in the first four shots at 45 cards gives the result 'greater than 45 cards', while four failures in the first four shots at 5 cards is reported as 'not greater than 5 cards'. Similarly for Scale III, a single fire in the first 10 shots at 45 cards is reported as greater than 45 cards while 10 failures in 10 shots at 10 cards is reported as 'not greater than 10 cards'.

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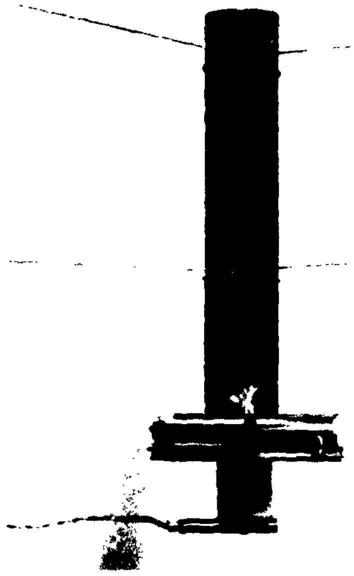

FIG.1.

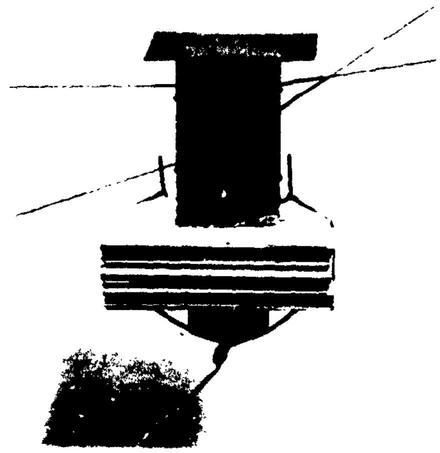

FIG.2.

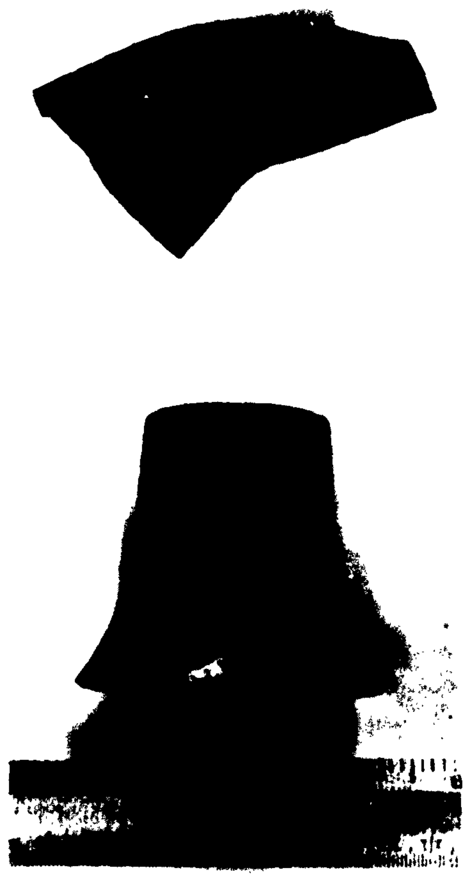

FIG.3.

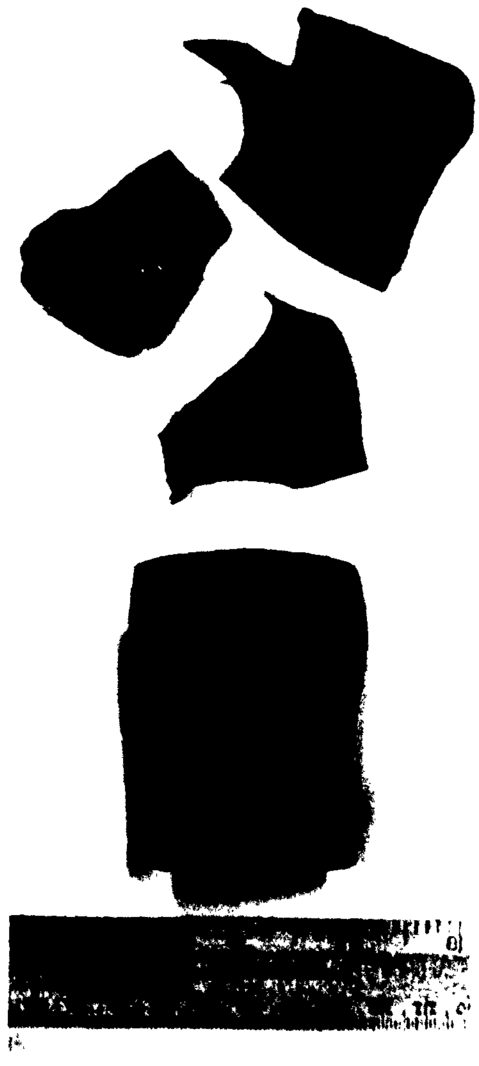

FIG.4.

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